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METHODS OF INSTRUCTION IN GENERAL GEOLOGY.[1]

BY H. S. WILLIAMS.

WHAT I can offer on this subject must be confined to a few suggestions upon points in which I see need of improvement, and some account of the various ways in which I am attempting to apply scientific method to the teaching of geology at Cornell University.

The science of geology, like the earth, from which it derives its name, bears a kind of maternal relation to the kindred sciences. As the materials discussed by physics, chemistry, and even biology come out of the earth, so the sciences treating of them have their springs of origin, and have been separated off from that more general science now represented by geology alone. As the more exact sciences have become organized they have set up their own standards and their own more precise methods, while geology has not become quite freed from some of the ancient crudities and myths.

This peculiar relation borne by geology to kindred sciences has much to do with the peculiarities of the methods in teaching it. Geology is less exact; there are more unsolved problems, or problems the solution of which is recognized as tentative; there are more points of contact with the dark regions of the unknown than are found in the other more specialized sciences.

This doubtless arises from the fact that as human knowledge has grown and the problems have become more scientifically interpreted, and the ultimate laws have been discovered, the principles involved have been relegated to their more special branches,—to physics, to chemistry, to astronomy, or to biology.

On the other hand, when these more precise sciences come across vexatious questions too complex for either alone to handle, they toss them into the broad lap of geology, so that we are left with the more mysterious and inexplicable phenomena of nature to wrestle with as best we may.

This broad and fundamental nature of the subject-matter of geology tempts a superficial treatment, and the teacher of geology needs to be specially on his guard lest he fall into the discussion of mere generalities. When we discuss the principles of geology we must generalize more or less. The facts are so many and so various that it is necessary to state in condensed form the laws which may best express the characteristics common to a great number of facts or phenomena. But when the geologist generalizes he is in greater danger than teachers of other sciences of being tempted to sacrifice science to the popular interest in wonders and curiosities.

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[1] Delivered at the meeting of the American Society of Naturalists, at Philadelphia, December 29, 1886.

The intimate relation borne by geology to the other sciences demands a broader knowledge than is required in them.

The geologist must apply to the solution of his riddles the laws of physics, astronomy, chemistry, biology, and mineralogy, and this brings with it the temptation to confine his instruction to the announcement of the theories, while referring the student to the special science concerned for the real solution of his problems.

Again, we may observe that geology, lying between the more thoroughly specialized sciences of modern times and the philosophies and purer literary branches of learning, has not altogether lost the effects of the scholastic methods of the literary school, nor has it fully attained the perfections of the scientific school.

Literary scholarship has for its ideals the skilful use of language as a means of expressing thought, of thinking and of interpreting thought. The subject-matter of this scholarship, as we scientists look at it, is language, and therefore the learning or mere memorizing of words and forms of verbal expression, including terse formulas and abstract statements, is valuable in itself, and is directly in the line of attainment of that kind of skill sought after in literary study. But verbal expression and definition is of secondary importance to the scientific scholar. To know simply names and definitions, laws, and, I may add, statistics, without the discriminative power of the eye, or ear, or touch, does not make a scientist. This acquirement bears no closer relation to scientific knowledge than the reading of an English translation of Cæsar's Commentaries bears to a knowledge of Latin. We would never think of calling him a classical scholar who was unable to read the original text. No more should we regard him a geologist, however well he might remember the text-book definition, who is unable to recognize and interpret geological phenomena in nature,—in the field and laboratory. Hence, in teaching geology, the mere ability to talk *about* geology, to say that Paradoxides is characteristic of the Cambrian, that Ichthyosaurus is a Mesozoic reptile, and a thousand other similar items of geological information, is of little or no practical use unless the student is taught to recognize an unlabelled Paradoxides when he sees it, and would know how to distinguish Cambrian rocks in the field. The subject-matter for the scientific scholar to acquire is found in the things and phenomena named and described, and not in the names or definitions.

In other words, the methods of literary instruction are of but limited value in teaching geology, and although we may begin with these methods, the teacher should not deceive himself with supposing that he is teaching science, or that the student is learning science, unless the lectures and text-book work are supplemented by drill in the laboratory and field. It may seem more dignified to stand up in a lecture-room before a lot of students and read off a lecture on geology, but the best results will come from the tramps and the hammerings in the ravines and railroad cuts and the study of hand specimens in the laboratory.

Our lectures may inspire the students to study, but most of what they learn will come by other methods.

We are obliged to use the lecture method, although not the ideal way of teaching science, on account of the large size of classes in our universities. Quizzes, and these written after every five or six lectures, I find of value in calling out study and thought upon the topics discussed in the lectures, and these I believe should always supplement the lecture for the best results.

In the lecture method there is one danger not met with when a good text-book is made the basis of recitations. Unless the lecturer is on his guard he will forget that his pupils are beginners, and neglect to state the essential details needed for a clear understanding of the topics under discussion. These details, when crowded by the multitude of topics he is tempted to consider, will be omitted by the lecturer because they seem to him so familiar.

To ward against this evil I give references to the pages in the more common text-books on geology, where the student may study more explicitly the subject lectured upon. I expect, too, that the student, who will acquire any exact knowledge of the science, must give some time both to this kind of book study and to the examination of specimens arranged and labelled specially to illustrate the facts discussed.

Again, it is important to so accentuate the lectures that the grand and important lessons shall not be smothered and quite lost to sight by the innumerable names and definitions and topics with which the lecture is necessarily filled. For I hold that, in teaching a class of ordinary college students general geology, it is far more important to teach them how to treat geological problems, what the grand questions are which the geologist meets, and the right methods of attacking, of thinking about, of interpreting them, than to teach definitions, technical formulas, or lists of associated facts.

The latter are all essential for the real geologist to master, but not in the lecture-room. They must be acquired by patient study of the more exhaustive manuals and original reports, and by actual laboratory and field practice.

The work for the lecturer upon general geology is to clearly present the principles of geology, to illustrate and explain the grand features of the science. He must teach what the science treats about, what and where the problems are exhibited, how they are explained, and what laws underlie the phenomena.

While the student gathers enough to excite his interest and enthusiasm, if possible, the method of stating the facts and theories should be such as to enable him to appreciate what there is to learn, rather than to convey any notion that he is getting from the lectures a knowledge of all the essential facts of geology.

We may be able in our lectures to teach the student the alphabet, so to speak, of the science, or even to teach him how to spell or frame sentences in terms of the geological language. We may succeed in showing him how to investigate and interpret geological problems. But I take it to be of essential importance to impress upon the student that the lectures are but an introduction, that the true place to learn geology is in the field and laboratory, and the true method, that of studying over in detail individual phenomena and facts.

This is not generalizing or popularizing the subject; it is making the lectures a means of scientific training, instead of allowing them to degenerate into a glowing account of the wonders of geology.

Geology may truly be a popular subject, because of the many remarkable events and phenomena it reveals, but it is not the remarkable, the unique, and the impressive facts of geology that are the most instructive.

The awful eruption that throws out lava and ashes from a volcanic vent, or tears off the top of a volcanic cone, is not so direct an illustration of the peculiarity of vulcanism as the little bubbles which puff up the cooling lava and testify to the presence of expansive vapors or gases in association with the molten condition of the rock.

The grand cañons of the plateau district are not so valuable as illustrations of the laws of river erosion as a simple rocky ravine composed of a few strata of alternating hard and soft strata, or even the rill along the roadside after a heavy shower. But, after having once grasped the principles of river erosion, its slowness of action, the smallness of the effect in proportion to the amount of water traversing the gorge, then the cañon does become an impressive illustration of the continuity of geologic dynamics over vast periods of time,—of the immensity of deposition of sediments,—of the grand results effected by the slow elevation of continents,—and it serves to convey some conception of the length of actual time with which the geologist has to deal.

Improvement may be made in the order of presentation of the topics.

In our standard text-books we frequently find what I may call the scholastic method followed,—a method which proceeds from the announcement of principles, laws, or technical definitions to the descriptions or illustrations of facts from which they have been drawn.

As an illustration the following may be taken from chapter second of Dana's Manual. The subject is lithological geology. First we are given a brief classification of the subject, then the definition of rock; then follow three sections in the following order: 1st, the elements constituting rocks; 2d, the mineral materials constituting rocks; 3d, the kinds of rocks.

For a geologist familiar with the general subject, and as a book of information arranged for ready reference, this is as good an arrangement as could be desired. But when the science is presented for the first time to the student, is this the order in which he must grasp the details of the subject for clear comprehension? I think not.

And why is it unnatural? Because the student is asked to take the results of an analysis before he is presented with the conception of the thing analyzed. He is led to form a synthetic conception of the objects studied, built up of definitions, rather than by analysis to increase his knowledge of the object by viewing it in new relations.

Rocks are at first parts of the earth, and among themselves they first differ in their physical relations of position, structure, form, and composition. The chemical and mineral properties are secondary in order of analysis; and the microscopic appearances presented by separate mineral species constitute a tertiary set of characters.

The teacher should have regard to this order of acquisition, although, after having named and briefly described the terms, they may become for his purposes mere definitive terms with which to describe the more comprehensive laws of the earth's formation.

For this reason there is propriety in uniting physiographic, structural, and dynamical geology as a first division of the general treatment of geology, following with the stratigraphical and palæontological part as a second division.

This plan, substantially, is followed in several of the more widely used text-books, as Phillip's, Credner's, Geikie's, Leconte's, and others.

In determining the order of presentation of the facts for particular cases, I examine the order in which the facts naturally develop in the process of investigation. As a general statement of what this order is, I find it to be from the more conspicuous, the more easily grasped, and the simpler, to the less evident, the intricate, and the fundamental. This same regard to the order of acquisition of ideas is applicable to the methods of illustration.

Every teacher of natural history has more or less use for diagrams, but I have thought that blackboard sketches, although crude, made while the explanation is going on, are often more effective in imparting the information desired than the more finished ready-made diagrams. The value of the blackboard sketch is in the fact that it emphasizes your words, makes them more vivid and expressive; with crayon in hand as you talk, the lines of the sketch become a kind of lineal gesture.

This result is particularly seen when the relations of two or more objects are expressed, or when serial or gradual changes or developments are considered, as in explaining Darwin's theory of the formation of coral reefs and islands, or the structure and growth of a common volcanic cone, or the effects of erosion in cutting through a series of hard and soft stratified rocks, and the relation of dykes to eruptive sheets, to volcanic lava-beds or fissure lava-fields.

All such phenomena are more vividly expressed to the beginner by blackboard sketches than by the more perfect diagram, and the reasons seem to lie in the fact that the student only appreciates the points to which his attention is definitely called; the large number of details expressed in the finished drawing tend to divert his thought from the essential few which are brought specially under consideration.

In teaching palæontology, in comparing genera, in pointing out variations and the relations of one form to another, I find the blackboard a great assistance.

A method specially successful of late in the teaching of biology suggests lines of improvement for the teaching of geology. The method I refer to may be called the exhaustive study of types, and such a book as Huxley's "Crayfish" may illustrate its application.

The secret of the value of this method lies in the process of taking a single object for minute and exhaustive study, examining it in all its several relations,—turning it around and throwing light upon it from every side, until the one thing is thoroughly understood in its every relation. The one object thus becomes a familiar and typical example of all the principles involved in its structure, function, or other relations. Afterwards, the widening of one's knowledge becomes a simple and also a systematic mental noting of likenesses and differences. The knowledge thus acquired, instead of being vague and general, becomes positive and precise.

In applying this method to teaching geology, I select a few characteristic phenomena, describe them particularly, noticing the individual details, and endeavor to make the one case thoroughly understood in all its important relations, so that it becomes the illustration of the several principles involved.

Thus, in explaining volcanoes, instead of spending the time with an enumeration of statistics and formulæ, crowding the lecture with all the information possible about volcanoes, the whole lecture may be spent upon Vesuvius, its environs and history, making vivid impression of one or two typical eruptions, and, by the aid of maps of the region, pointing out the precise phenomena in the locality, sequence and results in building a cone and making volcanic deposits. With a clear notion of one such typical volcano, it is a simple matter to classify and point out the kinds of volcanoes,—the pure tufa eruption, as at Monte Nuova, the continuous lava flow, as in the Sandwich Islands,—and by means of the grand eruptions recorded of Skaptar Jokul, to gain a conception of fissure eruptions and the nature of the vast lava-fields covering now such large tracts of the surface, but without the conical mountain peaks which we naturally associate with igneous eruptions.

In the same way in treating of river dynamics, instead of brief descriptions of the great rivers of the globe, the amount of their erosion and sedimentation, the volume and rate of their water-flow, etc., presenting a great number of condensed statistics about many rivers, a better way is to spend the time in explaining the facts and their interrelations for a single typical river.

No better example can be found for us than our great river Mississippi, so thoroughly studied and reported upon in Humphrey and Abbott's monograph. For illustration of the principles of erosion a familiar ravine, near by, is better than a large river-gorge at a distance. Niagara may well serve to illustrate the rate of erosion and as a short measure of geologic time. The cañons of the plateau district are illustrative of the laws of continuous depositions, of slow but great elevation, and furnish a longer but conceivable measure of time for geologic events.

So in all cases, where it is possible, selection should be made of a familiar and typical example, and around it should be gathered the details of facts and phenomena which will illustrate the principles discussed. By communicating a clear, detailed conception of the one example, the indistinctness and often bewilderment arising from the array of a multitude of statistics in regard to many examples is avoided.

At first sight this method may appear like a mere popularizing of a science, and—the aspect which might be so called,—the attempt to make comprehensible and therefore interesting, what is generally not so, is worth seeking after.

Is it not this very element of exciting interest, of pleasing the hearers or readers, that made the writings of Lyell and the lectures of Louis Agassiz so attractive and also so instructive?

The boys in college learn the principles of geology in the same way that we learn new laws and principles in our deeper investigations. It is facts and phenomena first, afterwards their interpretation; and unless they gain a vivid impression of the former, they will come short of grasping the latter. The other method of memorizing the statements of the laws and principles of the science, without any clear conception of the facts to which they apply, is only a knowledge of words; it is not science; and such knowledge has no scientific value.

In *field* and *laboratory* work the main point is to teach the student to observe, to record, and properly to interpret facts as they occur in nature. This is not accomplished by simply walking over the ground and pointing out the phenomena to the class. In one way and another they must be led to see for themselves; they must gather the facts, study and arrange them. The teacher may show them how to make sections, and how to gather facts and specimens. Section after section may be made through similar series; geographical localities, altitude, thickness, dip, lithological character, and fossils should be observed, and notes and materials brought in for study. After numerous sections are thus in hand, my plan is to call for a report upon the region or formations examined, asking for detailed answers to the questions, What are the faunas? What are the differences in the several sections? What changes are seen in the nature of the deposits on passing upwards? What are the names and characters of the individual species? etc. If the student wishes to perfect himself in palæontology, I set him at work on the local palæontology and stratigraphy, causing him to make comparison of sections, of association of species and individual variations, as well as drilling him in the identifying of genera and species; using the local facts, because I find better results from the deep and exhaustive study of what is at hand and is capable of such exhaustive treatment than is possible by the method of discursive rambling over a greater number of facts.

The materials ready at hand for us at Cornell University are Devonian; but the student who has learned accurately to identify species of a Devonian fauna has learned the relative importance of characters for classification; has learned the nature of variability, the relation of species to geological horizon, the modification of specific types with retention of generic features on passing from zone to zone; has studied the range and distribution of the species; has gained a conception of what faunal association is and how it is related to the lithological character of the deposits; I say the man who has grasped these details of the science by the use of Devonian material alone is ready to undertake investigations in any geological period, from the Cambrian to the Tertiary. The facts may differ, but the methods of research will be the same; and this method and skill cannot be attained by any amount of the mere memorizing of the names of a labelled collection of fossils.

It is a mistaken view to imagine that that kind of acquirement which only removes the Megatherium, the Ichthyosaurus, the Trilobite, and the Palæoniscus from the region of wonderland to a place among the things we have seen, is geology. So long as we use our museums as curiosity-shops and cover our ignorance with Latin nomenclature, we cannot expect to lift our science out of the region of crudities.

There is, however, some value to be derived from studying over labelled collections, but this must not be without the study of the fossils as they occur in the rocks, and the determining of the characters, the names, and the horizon, each man for himself.

And if the rocks are crystalline and not fossiliferous, this determines beforehand that there are not present the best facilities for the study of palæontology, although great museums may have been accumulated.

The natural rock foundations of the region in which a university is built thus decide the particular part of geological science which may be there taught most successfully.

To this fact may be traced the explanation why Harvard, Yale, and Amherst have been so prolific in physical geologists and mineralogists; why New York State has given us so many palæontologists; why the geologists of Pennsylvania have taught us so much about stratigraphy and the structure and products below the surface.

In each institution the natural advantages found in the accessible rock exposures of the region should be not only carefully studied, but should be made a prominent feature in all the advanced work of the college.

In conclusion, I would remark that (*a*) the fundamental nature of the subject-matter of geology, with its many still unsolved problems, its many mysteries, its many unique and wonderful facts, will tempt the instructor to deal with generalities, to rest satisfied with a superficial rather than a scientific presentation of his subject. As a means of escaping this danger I suggest a careful attention to the natural order of the acquisition of the facts,—a following of the analytical order, from the conspicuous, the evident, the general, to the special, the hidden, the individual, or, to use another form of expression, follow the order of induction from the concrete, the typical, the illustrative, to the principles involved to the formulation of the laws of nature.

(*b*) Further, I would suggest the great value of selecting a single typical illustration of each general principle, presenting it with considerable attention to details, pointing out its specific characteristics. This example, then, may be adopted as a standard for comparison with other cases which offer modification of the laws involved in the first typical case.

(*c*) In field and laboratory work the same method may be applied with good results. In this part of the study problems which are accessible, in which the student can investigate the details and gather numerous statistics mutually bearing upon each other, are to be selected. In this way the region in which he studies becomes one of the chief factors in developing his powers of investigation and in showing him how to interpret nature. He thus studies nature from the original text, instead of reading merely the translations made by others.

(*d*) In all the various departments of the science I would seek to teach the student precision and definiteness in his knowledge, and accuracy in his modes of thought, by applying the simple rule of teaching much about a few things, instead of attempting to say a little about a great many things.